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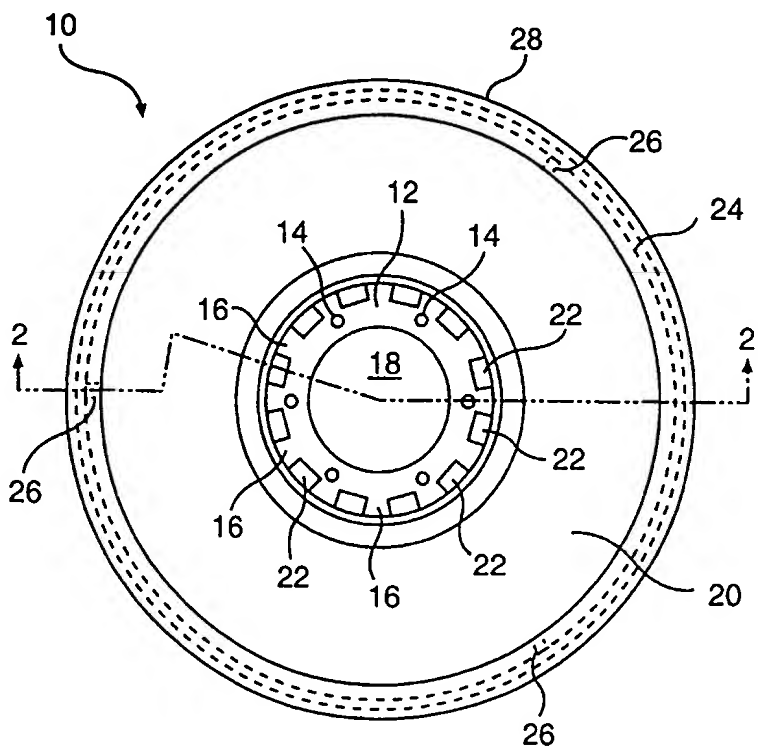
(54) Title: COMPOSITE FLYWHEEL FOR ANGULAR MOMENTUM DEVICES AND THE LIKE AND METHOD OF MANUFACTURING SAME

(57) Abstract

A flywheel (10) for high angular momentum devices such as gyroscopes and the like, including a drive member (12) having a splined outer portion (16), and a spacer member (20) having a splined inner portion (22) positioned around the drive member (12). The splined inner portion (22) of the spacer member (20) is in cooperating relationship with the splined outer portion (16) of the drive member (12), thereby enabling the drive member (12) to impart a rotational drive force to the spacer member (20). The splined connection between the drive member (12) and the spacer member (20) enables the spacer member (20) to float outwardly from the drive member (12) under centrifugal loading. The flywheel (10) further includes an inertia ring (24) positioned around the spacer member (20) for providing the desired inertia mass for the flywheel (10). The outward movement of the spacer member (20) under centrifugal loading results in its compression against the surrounding inertia ring (24) to reduce radial tension forces in the flywheel (10) when rotated. A method of manufacturing the flywheel (10) is also provided which places the spacer member (20) in a state of compression.



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COMPOSITE FLYWHEEL FOR ANGULAR MOMENTUM DEVICES AND THE LIKE AND METHOD OF MANUFACTURING SAME

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an improved flywheel, and more particularly, to a composite flywheel for high-speed rotational devices, such as momentum wheels for orbital insertion, gyroscopes and the like, and a method of manufacturing the flywheel.

Brief Description of the Related Art

Flywheels have been successfully used to provide gyroscopic stabilization and other functions for various types of devices and vehicles, such as satellites, space vehicles and the like. Flywheels typically include a weighted outer portion or ring (inertia mass) which is rotationally driven or spun at a predetermined rate, thereby generating angular momentum. The angular momentum generated by the rotating flywheel is advantageously used in a known manner for stabilization, satellite insertion, and/or other known applications.

In certain applications, such as in space vehicles and satellites, the flywheels must be relatively small and lightweight, due to the space and weight limitations inherent in these types of applications. Thus, flywheels made from lightweight composite materials have been developed for these type of applications. On the other hand, a flywheel used in satellite

applications must be driven at a high rotational speed to generate sufficient momentum to enable the instrument to provide the stabilization and/or other function(s) desired.

One problem with known composite flywheels is that the speed at which the flywheel can be rotated is strictly limited, due to the fact that centrifugal loading causes radial and tangential forces in the flywheel. Known composite flywheels fail when operated at high speed generally as a result of the radial tension. For example, no composite flywheel with an inertia mass over a certain value has ever been able to pass a Spin Test established by NASA, wherein the flywheel is driven at 30,000 RPM with a stop and restart every fifteen minutes for two hours. Failure of this type of instrumentation, particularly when used for vehicle stabilization, can result in the loss of expensive equipment and/or serious injury or death to occupants of the vehicle.

Thus, a need exists for an improved lightweight flywheel to provide high angular momentum, which enables the systems to operate at a lower weight and at a higher speed without structurally degrading when compared to known flywheels.

SUMMARY OF THE INVENTION

A primary of object of the instant invention is to provide an improved flywheel which can be used for lightweight, high performance, high inertia flywheel applications.

A more specific object of the instant invention is to provide an improved composite flywheel which can pass the NASA 30,000 RPM Spin Test (stop/start every fifteen minutes for two hours) with a higher inertial mass than any other known flywheel that has passed this test.

A further object of the present invention is to provide an improved flywheel which minimizes or eliminates radial tension forces within the flywheel, thereby enabling the flywheel to operate at higher speeds and momentum as compared to known flywheels.

Still another object of the invention is to provide an improved flywheel which is lightweight, durable and relatively inexpensive to manufacture.

Another object of the instant invention is to provide an improved flywheel that can be adapted for use with any rotational energy storing mechanism.

A further object of the instant invention is to provide an improved composite flywheel which can reliably be used in gyroscopic stabilization applications, and, more particularly, in lightweight, high performance, high inertia satellite orbital insertion applications.

Yet another object of the invention is to provide a method of manufacturing a flywheel, which method further enhances the operation and reliability thereof.

These and other objects are achieved by the present invention, which provides a flywheel including a drive member or ring having a splined outer portion, and a spacer member having a splined inner portion positioned around the drive member, wherein the splined inner portion of the spacer member is in a cooperating relationship with the splined outer portion of the drive member, thereby enabling the drive member to impart a rotational drive force to the spacer member. The splined connection between the drive member and the spacer member enables the spacer member to float outwardly from the drive member under centrifugal loading resulting from high speed rotation of the flywheel, while still maintaining a driving connection therewith. The flywheel further includes an inertia ring positioned around the spacer member for providing the desired inertia mass for the flywheel. By allowing the spacer material in the flywheel to float outwardly during rotation into a state of compression against the inertia ring, radial tension forces in the flywheel are significantly reduced.

In accordance with another aspect of the instant invention, the spacer member is provided on the flywheel in a state of compression within the inertia ring. In accordance with a preferred embodiment of the invention, the inertia ring is made of metal, such as steel, and a graphite and epoxy overwrap is provided around the inertia ring. The composite overwrap uses a room temperature curable resin to allow the stress state in the ring

and space member to remain unchanged during resin cure of the overwrap, and to eliminate any potential for delamination between the inertia ring and the overwrap. The compression forces from the compressed spacer member are reacted by the inertia ring and overwrap. The spacer member is preferably made from a Kevlar reinforced nylon material. The spacer member preferably has a tapered configuration, wherein the upper and lower surfaces thereof are tapered inwardly toward the inertia ring, in order to reduce the radial stresses in the portion of the spacer member that is not restrained by the inertia ring. A plurality of spaced connectors, such as pins, are used to secure the inertia ring to the spacer member.

In accordance with another aspect of the invention, a method of manufacturing the flywheel is provided, wherein the method includes: providing a drive ring having a splined outer portion;
placing a spacer member with a splined inner portion around the drive ring such that the splined inner portion of the spacer member is in a cooperating relationship with the splined outer portion of the drive ring; and placing an inertia ring around said spacer member. Preferably, the step of placing the inertia ring around the spacer member, includes: shrinking the spacer member by a cooling process; installing the inertia ring around the spacer member; and warming the spacer member to ambient temperature. This process causes the spacer member to be in a state of compression within the inertia ring when the flywheel is at ambient temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features, objects and advantages of the subject invention will become apparent from a study of the following detailed description of the invention when viewed in light of the accompanying drawings, in which:

Fig. 1 schematically shows a top view of one embodiment of the flywheel of the present invention;

Fig. 2 shows a sectional view of the flywheel of Fig. 1 along line 2-2 thereof;

Fig. 3 shows a sectional view, similar to Fig. 2, of another embodiment of the instant invention;

Fig. 4 schematically shows a partial, cut-away view of an exemplary embodiment of the floating connection within the flywheel, in accordance with the present invention; and

Fig. 5 shows a view similar to that of Fig. 5, wherein the spacer member of the flywheel is compressed outwardly due to centrifugal loading.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, wherein like reference numerals designate similar parts throughout the various views, the reference numeral 10 is used to generally designate the flywheel of the instant invention. The flywheel 10 includes an inner or drive member ring 12 constructed to enable the drive ring 12 to be connected to a driving device (not shown),

such as a motor. The drive ring 12 may be made of any suitable material having sufficient strength for the particular application in which the flywheel 10 is used. The drive ring 12 is preferably made of metal, such as high strength steel, when the flywheel is intended for high performance, high inertia applications. In the embodiment of Fig. 1, a plurality of spaced bolt holes 14 are provided in the drive ring 12 for facilitating connection of the flywheel 10 to the intended driving device (not shown) and to hold upper and lower restraining washers (not shown) which preclude vertical translation of the flywheel relative to the driving device.

In accordance with an important aspect of the instant invention, the drive ring 12 is provided with a plurality of splines 16 spaced around the outer portion of the drive ring 12. The splines 16 may have any suitable shape and may be provided in any suitable configuration around the drive ring 12. While in the embodiment of Fig.1, the drive ring 12 is shown as having an open interior 18, the drive ring 12 may be provided without the open interior 18, depending on the particular manner in which the drive ring 12 is to be connected to the particular driving device used for a particular application. It is noted that the instant invention is directed to the flywheel 10 itself, and not to flywheel driving devices, bearing, or other aspects of known devices or instrumentation in which the instant flywheel may be used. Thus, no further details on such other devices are provided herein, as one skilled in the art can readily implement the instant

flywheel in any suitable application from the description of the invention herein.

The flywheel 10 further includes a spacer ring or member 20 positioned around the drive ring 12. The spacer member 20 may be made of any suitable material, such as a composite material, preferably as lightweight as possible. In accordance with a preferred embodiment of the invention, the spacer member 20 is made from a Kevlar reinforced nylon material, such as the material sold under the trade name Hedlar Z, but any other suitable, durable and lightweight material could be used.

In accordance with an important aspect of the instant invention, the spacer member 20 is provided with a plurality of splines 22 around the inner portion thereof. The splines 22 on the spacer ring 20 and the splines 16 on the drive ring 12 are each shaped relative to one another in a manner which enables the respective splines 16 and 22 to fit into a cooperating relationship and to allow the spacer member to float radially without interference/restraint. This cooperating relationship between the respective splines 16 and 20, as shown most clearly in Fig. 4, connects the spacer member 20 to the drive ring 12 in a manner which enables the drive ring to transfer a driving force to the spacer member. The purpose and advantage of this splined interconnection between the drive ring 12 and the spacer member 20 will be explained in more detail hereinafter. The spacer member 20, may, for example, be milled to create the desired shape.

As seen most clearly in Fig. 2, the flywheel 10 further includes an inertia ring 24 positioned around the spacer member 20, for providing a desired mass for achieving a desired angular momentum with the flywheel 10 when rotated. The inertia ring 24 may be made of any suitable material which provides the desired inertia mass, and it is preferably made of a metal, such as high strength steel. As shown in Fig. 2, the inertia ring 24 is preferably connected to the spacer member 20 with a plurality of spaced connectors 26, such as tapered pins or the like. For example, three sets of pins 26 may be used to connect the inertia ring 24 to the spacer member 20, wherein the sets of pins are spaced equally around the diameter of the inertia ring 24.

The flywheel 10 also preferably includes a wrapping of material defining an overwrap 28 around the inertia ring 24, to further help secure the inertia ring 24 to the spacer member 20.

The overwrap 28 is preferably a composite material, and, more particularly, a graphite fiber/room temperature cure matrix material hoop wrap, but any suitable material may be used. In accordance with an important feature of this embodiment of the invention, the overwrap 28 uses a room temperature curable resin system, such as the resin system sold under the trade name Siloxirane, as the matrix for the overwrap 28. The advantage achieved by using a room temperature curable resin in the overwrap will be explained hereinafter.

In accordance with an advantageous feature of the instant invention, the spacer member 20 is preferably provided in a state of compression within the inertia ring 24 and overwrap 28 when the flywheel 10 is at ambient temperature. In order to reduce stress in the compressed spacer member 20, the upper surface 30 and lower surface 32 thereof are preferably tapered inwardly toward the inertia ring 24, as shown in Figs. 2 and 3. The compression of the spacer member 20 can be achieved, for example, when manufacturing the instant flywheel 10, by cooling, and thereby shrinking, the spacer member 20, placing the inertia ring 24 around the shrunken spacer member 20, and then warming the combined elements to ambient temperature. This process creates a shrink fit for the spacer member 20 within the inertia ring 24, as a result of a mismatch in the coefficient of thermal expansion between the material comprising the spacer member 20 the material comprising the inertia ring 24. The compression forces from the compressed spacer member 20 are reacted by the inertia ring 24 and the overwrap 28. Using a room temperature curable resin in the overwrap 28, enables the residual compression state of the spacer member 20 to remain unchanged during resin cure and eliminates any potential for delamination between the inertia ring 24 and the overwrap 28. It is noted that, while providing the spacer member 20 in a compressed state is advantageous for high inertia applications, this feature is optional and the invention is not limited thereto. Balancing weight(s) or

preferably local material removal (not shown) may be provided behind the overwrap 28 if necessary or desired to balance the flywheel 10.

An alternative embodiment of the instant invention is shown in Fig. 3, wherein the steel inertia ring 24 and graphite/resin overwrap 28 are replaced by an inertia ring 24' comprised of a preformed wire wound matrix material. In this alternative embodiment, the spacer member 20 also preferably has a shrink fit within the inertia ring 24' as described above.

The importance of, and advantages achieved by the splined connection between the drive ring 12 and the spacer member 20 will now be described with reference to the exemplary embodiment of the invention shown in Figs. 4 and 5. As explained above, the drive ring 12 and the spacer member 20 each include a plurality of splines 16 and 22, respectively. The splines 16 and 22 fit together in a cooperating or complementary relationship, and allow a driving force on the drive ring 12 to be transferred to the spacer member 20, and ultimately to the inertia ring 24. This splined connection enables the flywheel 10 to perform its high speed rotational function when driven by an appropriate driving device.

Fig. 4 shows the flywheel 10 in its non-driven or non-rotating condition. In this condition, the respective splines 16 and 22 have a relatively close or tight fit against the spacer member 20 and drive ring 12, respectively. As shown in Fig. 5, however, the splined connection enables

the spacer member 20 to compress or float outwardly under centrifugal loading caused by the rotation of the flywheel 10 when in operation. This outward compression causes the splined portions of the drive ring 12 and spacer member 20 to separate from one another by a given amount during operation of the flywheel. By allowing the spacer member 20 to compress outwardly by centrifugal loading, radial tension forces are advantageously eliminated in the spacer member 20 during operation. By eliminating, or even just reducing the radial tension in this manner, the instant flywheel 10 is able to achieve a higher inertia without structurally degrading, as compared to known flywheels.

The initial state of inward compression of the spacer member 20 as a result is its shrink fit, as described above, tends to offset some of the outward tension forces from the centrifugal loading in the unrestrained tapered portion of the spacer member, thereby further enhancing the structural integrity of the instant flywheel 10. Due to the relative depth of the splines 16 and 22, the splines remain in a cooperating relationship even when the spacer member 20 floats outwardly, as shown in Fig. 5, thereby always maintaining a driving connection between the drive ring 12 and the spacer member 20.

While the splines 16 and 22 on the drive ring 12 and spacer member 20 have been described and shown herein as having a sprocket or mechanical gear-type configuration, this configuration is only a preferred

embodiment, and the particular configuration of the splined connection may vary and be provided in any suitable form which enables the spacer member to float outwardly from the drive ring 12 while still maintaining a driving connection therewith. In other words, the instant invention is not limited to the particular embodiment of the splined connection shown in the drawings.

The flywheel 10 may be made in any suitable overall size depending on the particular application in which the flywheel 10 is intended to be used. The instant flywheel 10 is particularly suited for use in lightweight, high performance, high inertia applications, such as satellite orbit insertion, regenerative braking and gyroscopic stabilization applications, but it may also be used in any suitable application where a flywheel-type energy storing mechanism is desired.

The particular order in which the respective parts of the flywheel 10 are manufactured and assembled may vary, and the method of the present invention is not limited to the particular order of the steps as set forth in the appended method claims, unless otherwise expressly indicated therein.

A flywheel constructed in accordance with the description above, and having an approximately five inch diameter inertia ring, passed the NASA 30,000 RPM spin test (stop/start every fifteen minutes for two hours) and has operated for over two months continuously at 24,000 RPM

with a higher inertia than has heretofore been possible with any known flywheel.

While the preferred forms and embodiments of the invention have been illustrated and described, it will be apparent to those of ordinary skill in the art that various changes and modifications may be made without deviating from the inventive concepts and spirit of the invention as set forth above, and it is intended by the appended claims to define all such changes and modifications which come within the full scope and true spirit of the invention.

WHAT IS CLAIMED IS

1. A flywheel, comprising a drive member having a splined outer portion, a spacer member having a splined inner portion positioned around said drive member, said splined inner portion of said spacer member being in a cooperating relationship with said splined outer portion of said drive member to enable said drive member to impart a rotational drive force to said spacer member, and an inertia ring around said spacer member, whereby upon rotation of the flywheel, the splined connection between said drive member and said spacer member enables said spacer member to move outwardly relative to said drive member into a state of compression against said inertia ring.

2. A flywheel as defined in Claim 1, wherein said spacer member is a composite material.

3. A flywheel as defined in Claim 2, wherein said spacer member is a fiber reinforced nylon material.

4. A flywheel as defined in Claim 1, wherein said inertia ring is made of steel.

5. A flywheel as defined in Claim 1, wherein said drive member is made of steel.

6. A flywheel as defined in Claim 1, wherein said spacer member is tapered inwardly toward said inertia ring along an upper and lower surface thereof.

7. A flywheel as defined in Claim 1, wherein said spacer member is in a state of compression.

8. A flywheel as defined in Claim 1, and further comprising an overwrap ring around said inertia ring.

9. A flywheel as defined in Claim 8, wherein said overwrap ring is a graphite fiber and resin hoop wrap.

10. A flywheel as defined in Claim 7, and further comprising an overwrap ring around said inertia ring.

11. A flywheel as defined in Claim 10, wherein said overwrap ring includes a room temperature cure resin as a matrix for said overwrap ring.

12. A flywheel as defined in Claim 11, wherein said inertia ring is made of metal.

13. A flywheel as defined in Claim 1, wherein said inertia ring is secured to said spacer member by a plurality of connectors.

14. A flywheel as defined in Claim 1, wherein said inertia ring is constructed of a wire wound matrix material.

15. A flywheel as defined in Claim 14, wherein said spacer member is in a state of compression.

16. A flywheel, comprising a drive member, a spacer member around said drive member, means for establishing a floating connection between said drive member and said spacer member to enable said spacer member to float outwardly from said drive member under centrifugal loading while still maintaining a driving connection therewith, and an inertia ring around said spacer member.

17. A flywheel as defined in Claim 16, wherein said inertia ring has a size which causes said spacer member to be in a state of compression.

18. A flywheel as defined in Claim 17, wherein said spacer member is tapered inwardly toward said inertia ring on an upper and lower surface thereof.

19. A flywheel as defined in Claim 18, wherein said inertia ring is made of metal.

20. A flywheel as defined in Claim 19, further including an overwrap ring around said inertia ring.

21. A flywheel as defined in Claim 20, wherein said overwrap ring includes a room temperature cure resin as a matrix for said overwrap ring.

22. A flywheel as defined in Claim 16, wherein said spacer member is shrink fit within said inertia ring.

23. A flywheel as defined in Claim 16, wherein said spacer member has a higher coefficient of thermal expansion than said inertia ring, thereby causing said spacer member to be in a state of compression at ambient temperature.

24. A method of manufacturing a flywheel, comprising the steps of:

- providing a drive member having a splined outer portion;
- placing a spacer member with a splined inner portion around said drive member such that said splined inner portion of said spacer member is in a cooperating relationship with said splined outer portion of said drive member; and
- placing an inertia ring around said spacer member.

25. A method as defined in Claim 24, wherein said step of placing an inertia ring around said spacer member, includes the steps of: shrinking said spacer member by cooling said spacer member; installing said inertia ring around said spacer member; and warming said spacer member to ambient temperature, thereby causing said spacer member to be in a state of compression within said inertia ring when said flywheel is at ambient temperature.

26. A method as defined in Claim 25, further including the step of connecting said inertia ring to said spacer member with a plurality of connectors.

27. A method as defined in Claim 25, further including the step of placing an overwrap of material around said inertia ring.

28. A method as defined in Claim 27, further including the step of using a room temperature cure resin as a matrix for said overwrap of material.

29. A method as defined in Claim 25, further including using a fiber reinforced nylon material for said spacer member.

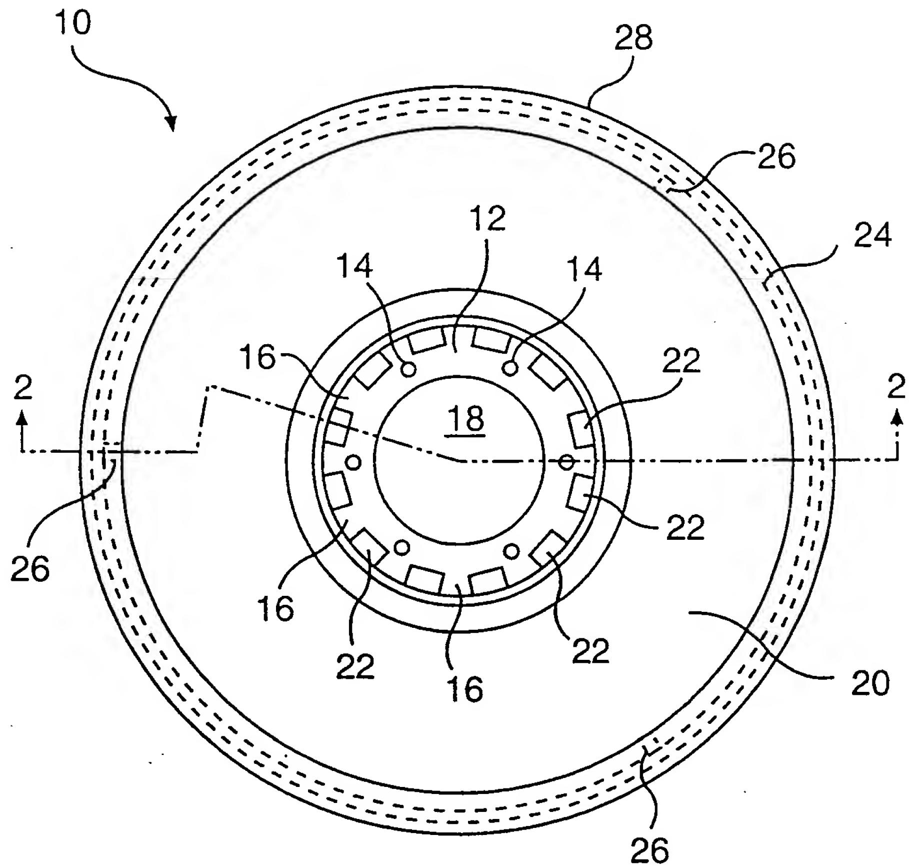

FIG. 1

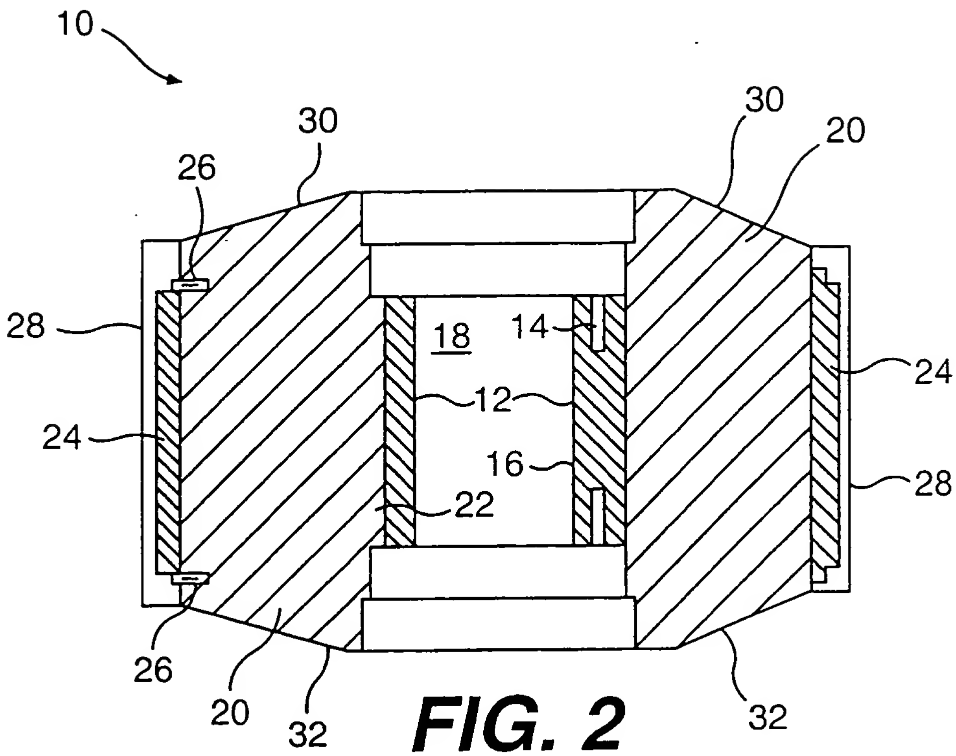
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FIG. 2

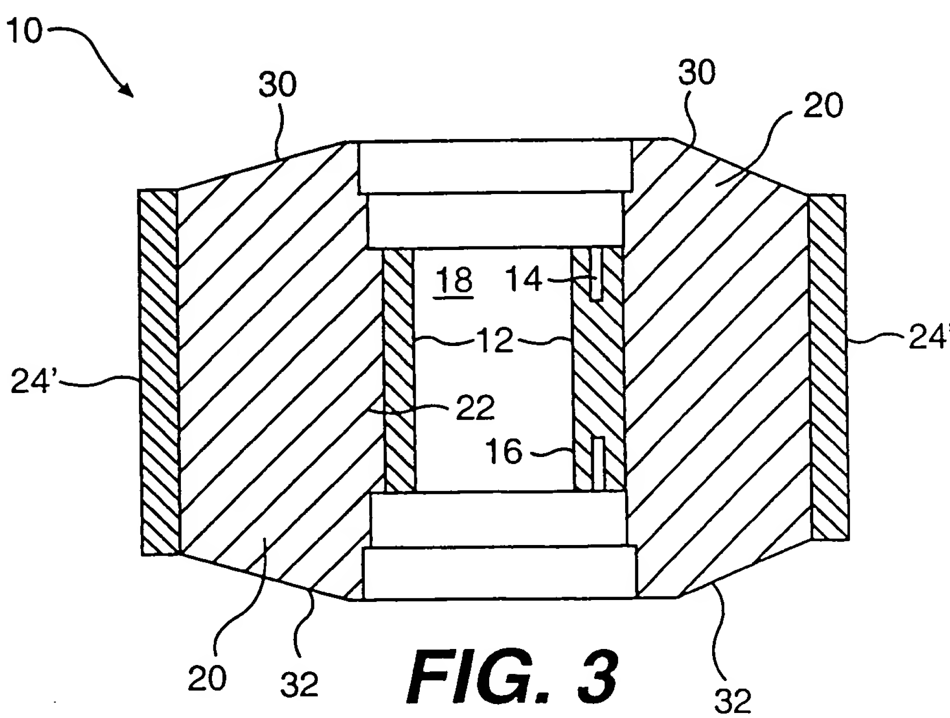
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FIG. 3

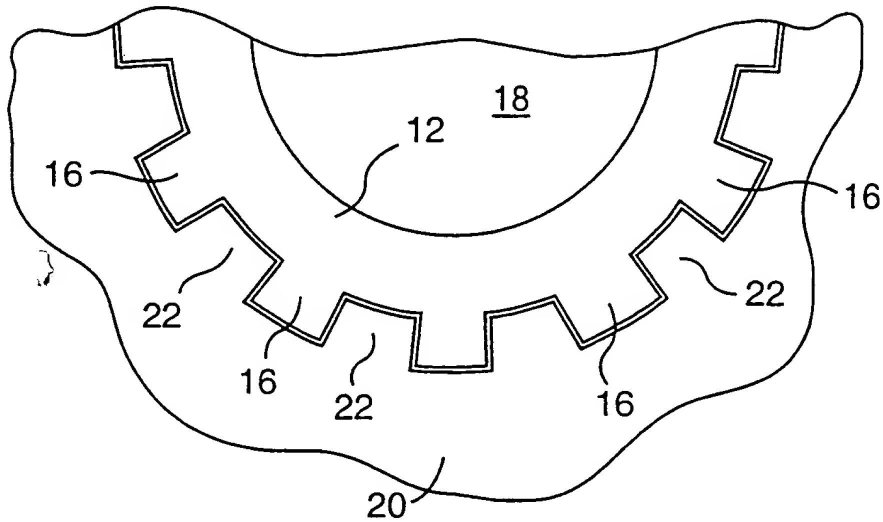

FIG. 4

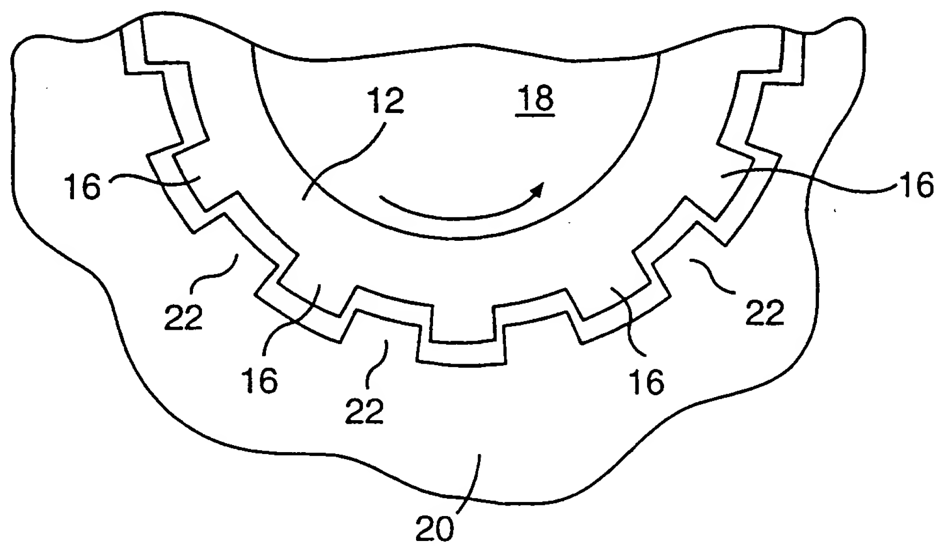

FIG. 5